



PHOTO: GERARD KELLY

Background Paper

Surveillance Systems to Facilitate Malaria Elimination

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Acronyms

ACD – Active Case Detection
CHAI – Clinton Health Access Initiative
CHW – Community Health Worker
D0AS – Day 0 Alert System
D3AS – Day 3 Alert System
DOT – Directly Observed Therapy
GIS – Geographic Information System
GPS – Global Positioning System
HMIS - Health Management Information System
ICT – Information and Communication Technology
IDNS – Immediate Disease Notification System
IRS – Indoor Residual Spraying
ITN – Insecticide-treated Net
LAMP – Loop Mediated Isothermal Amplification
MCDI – Medical Care Development International
MCN – Malaria Case Notification
MEEDS – Malaria Early Epidemic Detection System
MIS – Malaria Information System
MoH – Ministry of Health
NMCP – National Malaria Control Program
PCD – Passive Case Detection
PCR – Polymerase Chain Reaction
PDA – Personal Digital Assistant
Pf – Plasmodium falciparum
RDT – Rapid Diagnostic Test
SDSS – Spatial Decision Support System
SMS – Short Message Service
UCSF – University of California, San Francisco
USAID – U.S. Agency for International Development
USSD – Unstructured Supplementary Service Data
VHF – Very High Frequency (Radio)
WHO – World Health Organization

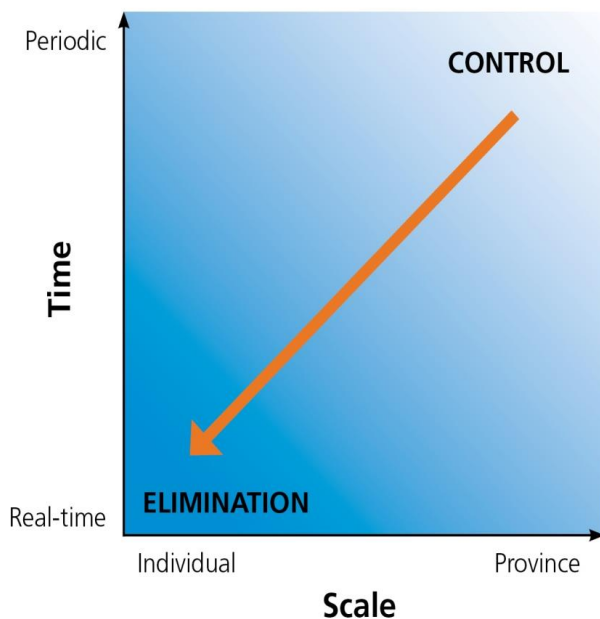
Introduction

Robust and responsive surveillance systems are critical for the success of malaria control and elimination.¹⁻⁵ In elimination settings, surveillance must be an intervention in which immediate action is taken in response to case identification.⁶ Data collection, analysis, output and response must occur quickly to identify symptomatic and asymptomatic cases, prevent onward transmission and reduce vectorial capacity. Information needs to flow from the community, be analyzed, and return to the local level framed as specific actions to identify and prevent additional cases. Access to data and ease of reporting at all levels are essential to ensure that local implementers can target interventions quickly and effectively.

When a malaria control program transitions to elimination, the surveillance system must change (Figure 1). These changes include rapid notification of individual cases, geo-referencing cases, and prompt response and foci investigation. Early in the development of a malaria strategy, planning should incorporate transitions that occur in the shift from control to elimination, even if elimination is a distant goal. This can help ensure that the surveillance system is flexible enough to adapt to the changes in scale and reporting time necessary when approaching elimination. Specifically, in an elimination setting, case reporting needs to shift from being periodic and aggregated at the district or provincial level to real-time reporting of individual geo-located cases. The advent of technologies that support surveillance for malaria elimination, including internet and communication technologies (ICTs), can facilitate many essential elements such as real-time reporting and case and intervention mapping. However, these technologies should only be applied where they are locally appropriate and when they can be used effectively.

Figure 1. Targeted surveillance and response in the shift to elimination

Darker blue indicates a more focused targeting.



In this background paper, we describe the characteristics of an ideal malaria elimination surveillance system that has the capacity to identify individual cases, analyze and share information and stimulate real-time action to prevent onward transmission. Through the examination of existing surveillance systems and ICTs for malaria and other diseases, we identify the essential components that can help achieve these goals. Finally, we discuss

challenges and opportunities for building an action-oriented surveillance system and provide recommendations for a system that functions as an intervention for malaria elimination.^{7,8}

This paper was informed by a review of published and grey literature, as well as key informant interviews with members of malaria control and elimination programs and experts in surveillance and information technology.

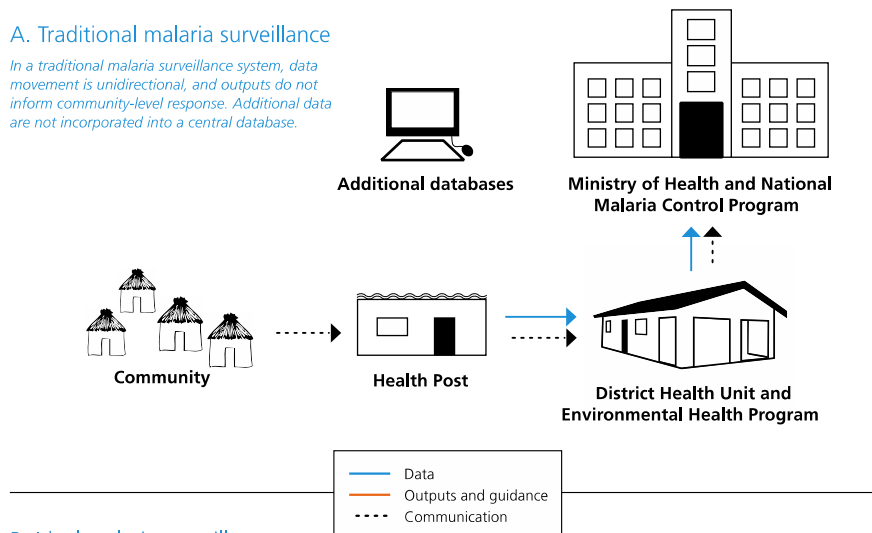
Characteristics of an ideal malaria elimination surveillance system

An ideal malaria elimination surveillance system collects and transmits data about cases and program activities swiftly, incorporates data from other existing surveillance systems in real-time and analyzes data to inform rapid response strategies.⁹

Figure 2. Malaria surveillance systems

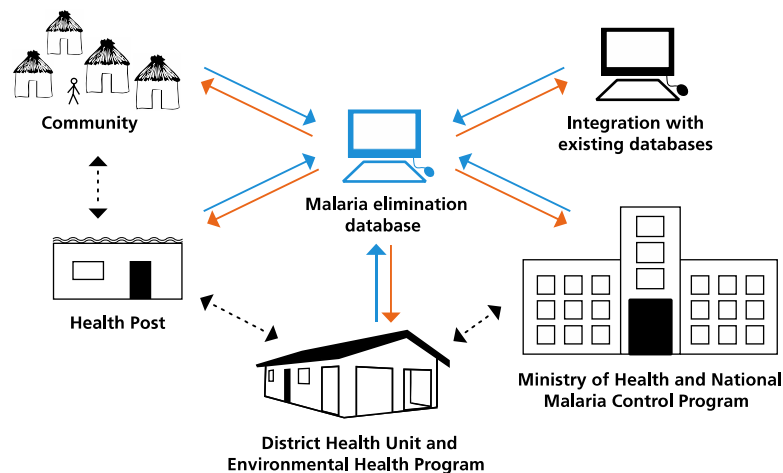
A. Traditional malaria surveillance

In a traditional malaria surveillance system, data movement is unidirectional, and outputs do not inform community-level response. Additional data are not incorporated into a central database.



B. Ideal malaria surveillance

In an ideal malaria surveillance system, all levels contribute data to a central database, the central database provides data analysis and guidelines to all levels, and communication is bi-directional.



The system directs customized outputs to stakeholders at local, national, regional and global levels to support decision-making at each level and ensure that plans and policies are evidence-based. Most importantly, information should be readily accessible to stakeholders at all levels to allow informed strategy development,

coordination between levels of the system, and local action. This type of broad access allows the system to bypass traditional vertical reporting structures (Figure 2). Once data analysis is complete, results can be shared directly with individuals working in communities and at the district, national and regional levels.

The system described above could be considered a modified version of a vertical single-disease surveillance system whereby parts of the system operate separately from an integrated health surveillance system. This separation is essential for malaria elimination to ensure that activities such as indoor residual spraying (IRS) or reactive case detection are carried out optimally. The vertical elements of this system, including data gathering and response, can be integrated into the larger health system once elimination has been achieved, as many of the specialized tasks required to achieve elimination are no longer required during prevention of reintroduction.

In addition to the individual elements of an ideal surveillance system for malaria elimination described below, attention to human resource capacity and sustained financial commitment are essential for successful implementation and sustainability of this comprehensive system. (For further discussion of human resources for malaria elimination, see UCSF Global Health Group Background Paper *Program Management Issues in Implementation of Elimination Strategies*, 2014).

A. Rapid and complete reporting

Data should be collected from the lowest level and in the most direct manner possible.¹⁰ This includes data collected passively at health facilities as well as case investigation and intervention data from community health workers and the district level malaria program. Data from existing information systems can be included; however, incorporating that information may be challenging due to a lack of uniform indicators. Consensus on key indicators or minimum essential data that a malaria elimination surveillance system needs to capture is fundamental. In Table 1, we provide a list of possible minimum essential data necessary to report a case, investigate and intervene. These activities are not always standalone actions and can often take place concurrently.

Table 1: Possible minimum essential data to report a case and elicit a response during malaria elimination

Surveillance Activity	Examples of Minimum Essential Data		
Case Detection	Name	Age	Parasite species
	Date	Address	Treatment given
	Gender	Diagnostic method	Patient type (e.g. migrant)
Case Investigation	Date		
	Case confirmation		
	Likely source of infection (including travel history and occupation)		
	Global Positioning System (GPS) coordinates of home and infection site		
	Treatment completed		
Intervention	DOT status		
	Date		
	Existing and new intervention coverage and adherence (e.g. active case detection [ACD], indoor residual spraying [IRS] and insecticide treated nets [ITN])		

Rapid reporting is a crucial element of a malaria elimination surveillance system. The World Health Organization (WHO) recommends that all cases be reported to district and national malaria teams immediately, whether by phone, very high frequency (VHF) radio, short message service (SMS), email, or via the Internet (e.g. using a GPS-enabled tablet).¹⁰ The system must be flexible to allow data entry by different means, rather than insisting on uniformity for an entire country. For example, for polio surveillance in Northern Ethiopia, VHF radios are used to report cases as neither Internet access nor reliable mobile phone coverage is available, but reporting is still in real-time and can trigger prompt response. Alternatively, health workers can report malaria cases immediately

using SMS in locations where mobile phone network coverage is available.^{11,12} The sustainability of each system is anchored by the use of available ICTs that do not require extensive maintenance by outside experts. What is most important is that methods for capturing data must be rapid, locally appropriate, feasible and sustainable by the malaria program. An additional consideration for the appropriateness of ICTs is whether they could potentially place users in danger. For example, using a tablet in an area with a high crime rate could place malaria surveillance staff at risk.

Complete, timely reporting is an essential element of a malaria elimination surveillance system. However, barriers exist to timely reporting, such as ease of access to standardized reporting forms, availability of telephone credit to call or send an SMS to report cases, and overburdened healthcare workers. Every effort should be made to reduce these barriers by making access to reporting methods as simple as possible. One example includes the provision of free or subsidized communication.

Capturing non-public sector sources of data is necessary for complete malaria reporting. In some populations, cases may present to traditional healers, religious leaders, military health services, informal drug sellers, or private pharmacies and healthcare providers before, or instead of, approaching public health facilities that are included in the surveillance system.^{13,14} Countries have implemented a range of approaches to capture cases that present outside of the public sector, including restricting access to antimalarials, making malaria a notifiable disease and incorporating private health facilities into the surveillance system. Oman, South Korea and Brazil regulate antimalarial drugs by ensuring they are available only in public sector health facilities which report to the national surveillance system.¹⁵ Swaziland and China have made malaria a notifiable disease to try to increase reporting and encourage more sectors to utilize the malaria elimination surveillance system.^{16,17} Malaria should be made a notifiable disease once incidence is low enough that malaria surveillance teams can investigate and report every individual case. Outreach campaigns should be conducted to ensure that both public and private providers are aware of changes to the infectious disease reporting system and understand how to identify and report cases.

Another approach is the inclusion of private providers, pharmacies, and laboratories in the network of reporting facilities. Pharmacies must keep detailed stock records and laboratories have diagnostic test results, and this data can be reported into the public surveillance system. However, this approach may encounter quality assurance difficulties as private sector testing practices may be monitored less closely for diagnostic errors. Working with intermediaries such as independent drug sellers or members of pharmacy franchises has been successful, exemplified by Tanzania's Accredited Drug Dispensing Outlets Program.¹⁸ Another option is to capture cases that present at private health care or pharmacy facilities by sending MoH staff to collect data on recent diagnoses or prescribing practices from non-traditional and private sector medical personnel.^{19,20} In all of these examples, strategies to encourage or enforce participation in the surveillance system may be necessary. Which strategies will be most effective depends on the local health care environment and the prevalence of malaria cases. However, without active engagement, data from these groups will be missed, hindering malaria elimination efforts.^{21,22}

Another means of improving reporting is to institute a 'zero reporting' policy. WHO recommends this policy for diseases targeted or considered for elimination, such as neonatal tetanus or polio. 'Zero reporting' requires that all reporting sites communicate the status of cases regularly, regardless of whether a new case has been detected.²³ This is an essential component of the polio surveillance system as it allows monitoring of ongoing activity, reduces missed data and helps identify locations where reporting is irregular or incomplete.²⁴ An example of the value of 'zero reporting' for malaria can be found in the reemergence of *P. vivax* on the island of Aneityum, Vanuatu. Had negative malaria diagnostic test results been part of routine reporting, the reintroduction of malaria may have been detected earlier and the subsequent outbreak possibly prevented.²⁵ In

locations where malaria may be close to elimination, a zero reporting policy could help prevent the tendency to become lax in surveillance as cases become rare.

A surveillance system should include monitoring of compliance and completeness. Comparing case reports from the malaria elimination surveillance system with antimalarial medication records from health facilities can help ensure that most cases are captured. Reporting completeness is an integral outcome measure for monitoring of elimination interventions and could be added to automated bulletins and reports. The closer a location is to elimination, the more important capturing each case will be, since a single case could lead to an outbreak and a resurgence of malaria.

An ideal malaria elimination surveillance system should support quality assurance of diagnostics. This is particularly important in low transmission settings, where the proportion of false positives will increase. Therefore, all positive results through passive case detection should be confirmed using additional diagnostic methods such as microscopy, polymerase chain reaction (PCR) or loop mediated isothermal amplification (LAMP). Additionally, attention should be paid to false negative results, as these can lead to untreated cases and an increase in the transmission reservoir. Each laboratory technician's ability to perform malaria diagnostic tests should be documented regularly, and external quality assurance methods must be in place. Other elements of quality assurance of diagnostics include ensuring that tests are performed correctly, and that results are input into the surveillance system. New technologies are emerging to improve diagnostic quality. For example, a point-of care rapid diagnostic test (RDT) reader that can give a quality assured result and transmit it rapidly is being developed and can potentially help improve data quality, the impact of which will likely be greatest in the private sector.²⁶

Finally, it is essential to discuss goals for monitoring antimalarial resistance and treatment effectiveness. A surveillance system that documents parasitemia after treatment (e.g. Days 3, 28, 42) can detect emerging drug resistance, indicate a lack of adherence where treatment is not provided through directly observed therapy (DOT), and have much greater implications than traditional therapeutic efficacy trials in sentinel sites. This data can then be used to inform strategies to address resistance and adherence challenges.

B. Incorporation of additional data

Incorporating external data into the malaria elimination surveillance system will allow decision-making to be based on a holistic set of indicators rather than exclusively on data collected by the malaria elimination program. Supplementary information could include:

- Entomological surveillance data
- Quality control data for diagnostic tests
- Supply chain data for testing and treatment supplies
- Prescription data from pharmacy databases
- Human population data, including census data
- Ecological data, such as land use and aquatic maps from the agricultural and forestry services
- Weather and climate data
- Human movement data

Other useful data exist, but may be more challenging to obtain and use. This includes:

- Counterfeit drug monitoring
- Real-time human movement data using mobile phone records
- Monitoring of inappropriate and ineffective drug prescribing practices

The malaria elimination surveillance system must be flexible enough to receive information from and export to external databases to ensure that malaria data are included in other systems as needed. However, including too

many inputs has the potential to overwhelm both the surveillance system and those who receive and interpret the system outputs. Information should be added to the system only when it is valuable for informing decisions and action. On Bioko Island, Equatorial Guinea, the malaria control program is working to incorporate ten years of historical data into its surveillance database, including household level census data, routine passive cases from the National Health Information System, cases detected through Focal Screening and Treatment campaigns, data from the annual Malaria Indicator Survey, entomological information, IRS monitoring, ITN distribution and coverage, stock control, human resources supply and training, quality assurance tracking and household level mapping using geographic information systems (GIS). The malaria control program is starting to use this data to inform decision-making and measure progress. However, the process of entering data, checking for errors and utilizing the data has been lengthy and has required the input of technical specialists.

C. Accessible data storage and management

In all settings, data should be accessible to key members of the health system.^{10,20,27} The database should be secure, available for use, sufficient for the quantity of data and appropriate for the context.^{11,28,29} In some locations, a cloud-based database will make the most sense because anyone with Internet access and administrative clearance can submit and obtain data in real-time. However, in locations where consistent access to the Internet is unavailable, a local database may be the best solution to ensure that work can continue during Internet outages. Such a system could link to the Internet whenever possible to synchronize data with the central database and ensure essential information is disseminated to stakeholders. If the Internet is entirely unavailable, data sharing can occur via regular visits, phone calls, SMS or VHF radio messages. Other system requirements should be considered, such as the need for a backup generator in case of power failure.^{16,30} Regardless of the type of data storage used, guidelines for timeliness of reporting must be established, such as the requirement in China and Swaziland that malaria cases be reported within 24 hours.^{16,17} Guidelines will depend upon the program's needs, resources and capacity to respond.

Data storage and management systems must be computer-based and should include a plan for ongoing maintenance.¹⁰ Ideally, software programs for storage and management of malaria surveillance data will be open-source, modifiable and easily maintained. In addition to technological requirements, there is a need for systems application developers and ICT specialists based in the government to maintain and modify the database as needed.

D. Analysis - automated and expert

A malaria elimination surveillance system should include automated data analysis to ensure timely outputs, as well as expert analysis for larger decisions about policy and programming strategies.^{7,10,11} Automation is vital because a malaria elimination surveillance system must receive and analyze data and output results quickly to identify outbreaks and inform response. Additionally, such a system will generate considerable amounts of data that could overwhelm available resources and personnel. The analysis and output from such an automated system will only be as good as the algorithms upon which they are based. Thus, technical expertise is necessary during development. It is essential to incorporate technical assistance and capacity building for malaria program staff at all levels to ensure the database is used effectively.

An example of automated analyses in malaria elimination is the Spatial Decision Support System (SDSS) in Vanuatu and the Solomon Islands.³¹ This GIS uses the time and place of malaria cases and intervention coverage to automatically classify areas according to risk and then generate specific response recommendations. More complex spatial modeling of case data with environmental and ecological variables (e.g. rainfall, altitude, vegetation) is possible, but has yet to be automated and incorporated into a surveillance system.³²

An important part of expert analysis is operations research, which uses data from the surveillance system to ensure that the most impactful and cost-effective interventions are used.^{3,28} Experts can design operations

research simulation models for malaria using surveillance data to generate a virtual representation of malaria activity and available interventions. Similar modeling was conducted in Haiti as part of an assessment of the feasibility of malaria elimination. Parasite prevalence data were used to better understand the optimal interventions and treatment strategies for various populations and locations.³³

Local malaria experts should participate in analysis, particularly in the interpretation of results. Local expert participation may include the operationalization of automated outputs to ensure that recommended interventions are feasible and reflect local conditions. Important factors such as political context or recent changes in land use can be difficult to capture in a surveillance-response system, and it is essential that local knowledge is incorporated in the analysis phase.

E. Customized output and feedback

An ideal malaria surveillance system should generate outputs automatically, including visualizations of analyzed data, work task lists, and reports for both internal use and external organizations and donors. However, not all data and analyses should be transmitted to all levels. Only the minimum essential results and feedback to generate response at the appropriate level is necessary. All outputs should be tailored to the level receiving them to ensure that they are neither lacking nor in excess. It is likely that this fine balance will need to be adjusted as the country moves toward elimination.

Once data have been analyzed, visualizing results is essential for effective targeting.^{7,34,35} Maps, graphs and tables allow easy interpretation of trends, summaries and work task lists. Outputs should demonstrate data trends at the lowest level possible so that cases can be tracked to the health center, village and household levels. Spatial representations of data using maps will range from simple plots of cases to predicted-risk maps based on geospatial models. Regular bulletins of results from the local, district and national levels should be distributed to inform malaria elimination teams of progress and emphasize their participation in a larger elimination strategy.¹⁰ If possible, this analysis should be automated so outputs can be distributed to key stakeholders regularly.

Outputs to the local level, including to surveillance officers and health facilities, should include specific work task lists to target local issues. For example, this could include instructions about reporting cases, conducting reactive case detection, and scaling up education or ITN distribution to anticipate the arrival of migrants. A good example of automated feedback exists in Cambodia where the system sends SMS to identify patients that are symptomatic after three days of treatment with artemisinin-based combination therapies. Based on that data, the surveillance system alerts appropriate health officials to investigate possible drug resistance.¹²

Communicating newly detected cases to the district level must happen as quickly as possible, whether via Internet, SMS or manually via telephone or VHF radio. This ensures that district-level malaria officers know when a case is identified and can conduct reactive case detection. Additionally, outputs at the district level should include monthly or quarterly reports of visualized trends so members of the malaria team can track incidence and understand changes over time. Easy-to-understand tables with dynamic information such as stock levels, number of malaria tests performed and staffing over time should be distributed and discussed regularly.¹⁰

At the national level, outputs are broader, showing trends in case incidence or drug resistance over time. An annual malaria report should be produced to compare current and previous data, using findings to inform program planning.¹⁰ Monitoring and evaluation of data are necessary to measure the value added of the malaria elimination surveillance system itself and understand how the system can be improved.

F. Targeted response

Response to malaria elimination surveillance system outputs needs to be timely, effective and targeted.^{10,20,36} At the local level, once community health staff receive outputs, including a work task list, they must take immediate action.^{37,38} This list may include case detection, checking ITN coverage and use, IRS and education about malaria prevention and response strategies. In addition, the responses carried out and their key operational details (e.g. timing, coverage, supply tracking) should be reported back to the surveillance system for supervision and monitoring purposes. Connecting outputs from surveillance systems to action is one of the weakest elements of most existing surveillance systems.

At the district level, responses include supervision, coordination, supply chain and intervention decisions. The outputs identify locations of highest incidence, weaknesses in implementation and where the district malaria office needs to take action.¹⁰ Responses may include ITN, RDT or medication distribution, or IRS team deployment.¹⁰ Additionally, supervision is simplified because district level staff receive reports of what village level staff *should* have done, which they can monitor and assess, feeding results back to the surveillance system.

At the national level, responses to surveillance outputs guide the larger malaria elimination strategy. Senior staff can interpret results to identify gaps, capacity-building needs or to change recommended response activities. Additionally, they can make decisions about how to address outbreaks.

The system with the most potential to guide targeted, rapid response to malaria surveillance data is the SDSS in Vanuatu and the Solomon Islands. Households are mapped using personal digital assistants (PDA) equipped with GIS and GPS.⁷ The surveillance system uses these data points to create automated maps of households, including coverage, incidence and additional geographic and entomologic data. Work task lists are generated for intervention and case management teams for each geo-located house they should visit. An SDSS that operates at the community and household levels is particularly appropriate in an elimination setting where targeted response is vital. However, despite the sophistication of this SDSS, resource and program management issues hinder effective use of detailed response recommendations.³⁹

Description of existing IT/surveillance systems

Currently, few comprehensive malaria surveillance systems exist that can collect, store and analyze real-time information. Many existing systems are limited in their geographic coverage, do not collect sufficient data to inform rapid response or are not connected to decision-making. We describe a number of these systems below to demonstrate the strengths and challenges of systems that already exist. Next, we discuss the links between local, national and regional surveillance systems and their importance for ensuring information sharing and coordination.

A. Existing malaria surveillance systems

Here we discuss the successful components of the existing surveillance systems in China, Swaziland and Zanzibar. While none of these systems are perfect, each contains elements of what an ideal system might look like and offer valuable lessons on how to conduct effective surveillance. Comparisons of these and other systems are highlighted in Table 2 and in more detail in Appendix B.

China

The strength of the Chinese Information System for Disease Control and Prevention is its timeliness, ease of reporting and intuitive 1-3-7 monitoring framework. The 1-3-7 framework dictates that malaria cases must be reported within one day, case investigation must occur within three days and foci investigation and increased prevention measures are implemented by day seven. The system is web-based, with all local health facilities reporting up to the level of commune hospital. Clear reporting and response guidelines are accessible to both malaria elimination teams and the public, emphasizing early detection and direct connection of reporting with

action. Recommended strategies vary by endemicity, with active fever screening every 10 days indicated in areas with high incidence, and passive and reactive case detection indicated in all areas.¹⁷

Swaziland

The strengths of Swaziland's malaria surveillance system include rapid case reporting through the Immediate Disease Notification System (IDNS), a surveillance system integrated with the notifiable disease system and surveillance outputs rapidly relayed to a team that can initiate a response. The health facility staff members use a toll-free phone number and promptly report cases to the IDNS. The system then automatically sends an SMS to the local NMCP program manager, as well as the surveillance team, with details of the case. Members of this group investigate the case within 48 hours. During the seasonal peak in malaria, additional surveillance agents were added for the first time in 2013 to improve case investigation and rate and timeliness of follow-up. Case details are collected at the health facility and include address and mobile phone number where available. The surveillance team then visits the case, collects additional information and conducts a response when necessary. All data are recorded on computer tablets that have built in GPS software and satellite maps, both of which support the surveillance team in locating households that need to be screened in response to a confirmed case. Confirmed cases and details of case investigations are reported weekly and monthly to the Health Management Information System, to ensure that it contains malaria data. Weekly goals, feedback and prioritization are provided to the surveillance officers to improve coverage rates and speed of follow-up and screening.

Zanzibar

The strengths of Zanzibar's Malaria Case Notification (MCN) are its rapid reporting and analysis outputs detailing geo-location of cases, through the Coconut Surveillance, a mobile application that guides and reports case follow-up. In 2008, the Malaria Early Epidemic Detection System (MEEDS) was established in Zanzibar, which involved weekly electronic reporting of malaria data using mobile phones. With the decline of malaria cases, MCN was started in 2012, which enables follow-up of all malaria cases, testing and treatment of household contacts and provision of preventive interventions and health information. MCN and Coconut Surveillance work together, cases are reported in real-time and then the tablet-based Coconut Surveillance platform alerts district malaria officers to follow-up, guiding them to visit the appropriate households to conduct reactive case detection and collect relevant information. In this system, surveillance is an intervention, where mobile reporting allows the collection of data in real-time that are used to guide a local response.¹¹ Additionally, MEEDS data feeds into malaria commodity supply information, informing procurement and reducing stockouts of commodities.⁴⁰ For example, RDT procurement is determined by the number of patients tested for malaria in the previous reporting period, which helps ensure that health centers are well supplied.¹¹

Table 2: Select malaria surveillance systems functioning at scale (For more detail on these and other systems see Appendix B)

Country	System description	Data Capture and Inputs	Outputs	Strengths	Challenges
Cambodia	<p>Malaria Information System (MIS) is a stand-alone system developed in MS Access to assess malaria transmission and intervention coverage. Two additional pilot systems communicate with MIS:</p> <ul style="list-style-type: none"> • Day 0 Alert System (DOAS) reports <i>Plasmodium falciparum</i> (Pf) real-time into a cloud-based MySQL database, • Day 3 Alert System (D3AS) reports Day 3 positive malaria smears with FrontlineSMS free software to identify resistance.^{12,41} <p>Population covered: >3M</p>	<p>Baseline and Imported data: MIS: topographic, census, health facility, intervention coverage to village level.</p> <p>Passive Case Detection (PCD) case notification:</p> <ul style="list-style-type: none"> • MIS: District level data entry reported to central database monthly. Data include species, severe malaria, deaths, RDTs by community health workers (CHW) and positive cases. • DOAS: CHWs and health staff send SMS for <i>Plasmodium falciparum</i> (Pf) cases from three pilot areas including species, age, sex, phone and village code. • D3AS: Same data as DOAS but only includes Pf cases still parasitemic after three days of treatment in areas of artemisinin-resistance. 	<p>MIS: Automatically generated five-page Ministry of Health (MoH) report generated monthly including tabular summaries, graphics and mapping to village level.⁴²</p> <p>DOAS: Real-time SMS alert sent to Provincial Health Department and National Malaria Center management. A Day-28 follow-up reminder is sent to the same plus the CHW and health center management. In a one-district pilot the system maps each newly diagnosed case using Google Earth.</p> <p>D3AS: Sends real-time SMS to management whenever a case fails to clear parasites by Day 3. Cases are mapped in Google Earth.</p>	<p>MIS:</p> <ul style="list-style-type: none"> • Covers all malaria-endemic areas, • Severe malaria and deaths tracked in system, • Malaria incidence and intervention coverage can be graphed and mapped to village level for any location or user group, • Automatically generated five-page monthly bulletin. <p>Pilot DOAS and D3AS:</p> <ul style="list-style-type: none"> • SMS and Internet-based real-time notification systems, • Integrated with MIS, • DOAS: free SMS donated by company, SMS reminder for patient follow-up. <p>Additional: Pilot web-based malaria commodity stock tracking system.</p>	<ul style="list-style-type: none"> • Pilot mobile technologies not yet taken to scale, • Large uncaptured private, migrant and military sectors, • Most data aggregated monthly, challenge to get real-time data, • Inconsistent decision making and response based on available data, • Does not capture time-to-case reporting, new interventions or intervention quality, • Case follow-up challenges, • No mapping to household level or where case was acquired.
China	<p>Two integrated web-based systems to achieve malaria elimination. One system is for febrile illness reporting, the other is for focus investigation and intervention tracking. Data is stored in an undisclosed database type at the National Centers for Disease Control and Prevention.¹⁷</p> <p>Population covered: >1.3B</p>	<p>Baseline and imported data: Maps to commune (sub-district) level, data from 49 sentinel sites.</p> <p>PCD case notification: Data entered at township level within 24 hours. Data include date, facility, reporting person, patient info and diagnostic result with method and treatment.</p>	<ul style="list-style-type: none"> • SMS alerts to Provincial Health Officers, • Monthly MoH report, tabular summary results, graphics and mapping to commune level, • “1-3-7 strategy” time tracking to case notification (one day), case investigation (three days), completed interventions (seven days). 	<ul style="list-style-type: none"> • Web-based system integrated with notifiable disease reporting, • Data fed into HMIS, • Nearly all malaria cases captured, • Very little missing data, • Rapid case reporting, • Diagnosis is confirmed by microscopy and PCR, • “1-3-7 strategy” is easy to use and understand. 	<ul style="list-style-type: none"> • Mobile technology not integrated, • Extensive sentinel site data, otherwise limited capture of baseline data, • Does not capture new interventions or intervention quality, • Some interventions possible in < 7 days, • No mapping to household or where case acquired.

<p>Solomon Islands / Vanuatu</p>	<p>Integrated Spatial Decision Support System (SDSS) framework using SQL programming language, MS Access database and MAPINFO® GIS software to achieve malaria elimination. Data are stored in a relational database, using local, provincial and nationally-based servers (three levels for backup).⁷</p> <p>Population covered: >90 k, implemented in four island provinces.</p>	<p>Baseline and imported data: Topographic and infrastructure layers, household locations, population data, IRS, ITN distribution coverage, mosquito breeding sites, malaria indicator surveys captured with GPS enabled tablets.⁴²⁴³</p> <p>PCD case notification: Health facility calls provincial center within 48 hours for data entry including date, facility, reporting person, patient info, diagnosis and method, and travel history.</p>	<ul style="list-style-type: none"> • Real-time case reporting, • Frontline and active case detection planning by household, follow-up list of households that did not receive intervention, • Routine reports every three months, • Tabular output, spatial analysis and graphics, • Maps: intervention planning, field-based operational, intervention coverage, positive case distribution, transmission foci classification and automated “area of interest” response. 	<ul style="list-style-type: none"> • SDSS includes extensive baseline data, • Rapid case reporting, • Automated GIS-based queries with high-resolution mapping, • Generates lists to support targeted action at the household level, • Facilitates budgeting by calculating distances and needed supplies, • Readily adaptable to other locations or systems. 	<ul style="list-style-type: none"> • Mobile technology not integrated, • Inconsistent decision making and response based on available data, • Does not currently capture time-to-case reporting, new interventions or intervention quality, • Human resource constraints, • No mapping to where case was acquired.
<p>Swaziland</p>	<p>Three systems: Health Management Information System (HMIS), Immediate Disease Notification System (IDNS) programmed in ASP.net with a SQL 2008 database for notification of 15 reportable diseases and Malaria Surveillance Database System (MSDS) built on ASP.net and SQL 2012 for malaria elimination.^{15,30,41} System uses GPS-enabled tablets programmed in ASP.net for baseline data, case investigation and interventions.</p> <p>Population covered: 1.2M</p>	<p>Baseline and imported data: Baseline topographic and infrastructure GIS layers. Household location, population data, IRS and ITN coverage.</p> <p>PCD case notification: RDT or microscopy-confirmed malaria cases are dictated through a toll-free hotline. Data are entered on a central server after which a surveillance agent receives an SMS with date, facility, reporting person, patient info and case number to conduct case investigation and intervention.</p>	<p>IDNS: Dictation to a toll-free hotline resulting in SMS alert to surveillance agent.</p> <p>MSDS: Monthly PowerPoint and annual narrative reports, tabular and graphic summary results, mapping to the household level. Maps include cases investigated, locations of positive cases, IRS and ITN coverage, potential breeding sites, risk maps, index case and households fully, partially, not screened, or identified for screening and not visited.</p>	<ul style="list-style-type: none"> • Integrated with notifiable disease reporting system, • Web-based system using mobile technology, • Cell phone provider issues free airtime, • Entire country covered, • Simple to use system for data collection, • Rapid case notification with simple methods, • Tablets for data collection reduce errors and turnaround time for data collection, entry, analysis, report generation, • Temporal-spatial analysis of case distribution. 	<ul style="list-style-type: none"> • Relatively low reporting completeness to IDNS, • Low case reporting from private sector health facilities, • Does not capture time-to-case reporting, new interventions or intervention quality, • Difficulty motivating agents to return to homes to achieve full coverage during active case detection (ACD), • No mapping to where case was acquired.

Thailand	<p>Stand-alone, web-based system programmed in Java. Data storage is in the Microsoft SQL Server 2005 relational database at Mahidol University. GPS-enabled tablets programmed in Java for patient follow-up, data captured in same server.^{4444,45}</p> <p>Population covered: >21M</p>	<p>Baseline and imported data: Malaria posts, hospitals, rubber plantations, malaria transmission area types, and village locations.</p> <p>PCD case notification: Case data entered at malaria clinic level within 24 hours. Data include date, facility, reporting person, patient info, diagnostic result with method and foci classification.</p>	<ul style="list-style-type: none"> - <i>Pf</i> case alerts to malaria clinic staffs' tablets within 24 hours, - Tablet-based follow-up form with dates for directly observed therapy and resistance monitoring, - Monthly MoH report, tabular summary results, graphics and maps, including mapping to <i>Pf</i> case's household and to where case was likely acquired. 	<ul style="list-style-type: none"> • Web-based system with mobile technology being integrated, • Implemented in large regions, covering all areas of multi-drug resistance, • Rapid case reporting, • Captures directly observed therapy (DOT), • Captures <i>Pf</i> resistance, • Mapping cases to where the infection occurred (e.g. forest sleeping location 10-20 days earlier). 	<ul style="list-style-type: none"> • Hospital-based cases in a separate system, • No military data, • Challenges with migrant and cross-border follow-up, • More baseline data should be captured, such as intervention coverage and forest sleeping locations, • Does not capture time to case reporting or intervention quality.
Zambia	<p>DHIS2 is a web-based health information system programmed in Java that is part of a three step strategy:</p> <ol style="list-style-type: none"> 1. Improved data quality at health facility level, 2. Reduce transmission with community-based interventions, 3. CHW case-based follow-up.^{4646,47} <p>Data storage is in Postgre SQL relational database. Mobile phones programmed in Java use the same database.</p> <p>Population covered: >6M</p>	<p>Baseline and imported data: Census data, administrative boundaries and GPS locations of health facilities and CHW posts.</p> <p>PCD case notification: Urban and rural health facility staff report weekly by mobile phone. Data include clinic visits, clinical cases, RDT-tested and positive cases, microscopy-tested and positive cases by age (<, ≥ 5 years), ACT and RDT stock tracking. CHWs report cases monthly by mobile phone.⁴⁷⁴⁸</p>	<ul style="list-style-type: none"> • Real-time case detection and response activities (not recorded in DHIS2), • Weekly, monthly and quarterly reports, with online access to data in real-time, • Graphs created and provided in real time to mobile phones or computers, summarizing malaria case reporting and stock data, with summary data from all areas reporting to the facility, • Maps and graphs display village and clinic-level malaria incidence. 	<ul style="list-style-type: none"> • Open source free web-based system fully integrated with HMIS, • Free technical support to core module, • Tables, charts and maps shared with all users with online dashboard⁴⁵⁴⁶, • Mobile technology fully integrated, • Stock management built into the system, • Implemented in large population, • Timeliness and completeness of data reporting tracked. 	<ul style="list-style-type: none"> • Limited capture of baseline data, • Case data not reported to DHIS2 in real-time, aggregated weekly (clinic) or monthly (community) data, Does not currently capture time to case reporting, interventions or intervention quality, • Remains to be determined if DHIS2 can support full malaria elimination surveillance system to household level.

<p>Zanzibar, Tanzania</p>	<p>Integrated system combining MEEDS (Malaria Early Epidemic Detection System), Coconut Surveillance and Malaria Case Notification (MCN).⁵¹⁴⁹⁻⁵² MCN includes rapid reporting and analysis outputs detailing geo-location of cases, through Coconut Surveillance. All cases are reported to MEEDS by health center staff via SMS into a PHP database. Coconut is an android application (html5 + CouchDB) that uses MEEDS data to guide household oriented index case follow up with cloud synchronization.</p> <p>Population covered: ~1.3M</p>	<p>Baseline/imported data: Topographical maps to household level.</p> <p>PCD case notification:</p> <ul style="list-style-type: none"> • MEEDS: Public health unit staff send an SMS for each positive case and a weekly summary. Data include all-cause visits, malaria tested/positive cases and age (>, <5 years). • Coconut: notifies malaria officers of cases immediately via SMS. • Patient and household follow-up with GPS enabled tablet. 	<p>MEEDS: Real-time case reporting via Coconut Surveillance, monthly MoH reports. Tabular summary results, graphics and mapping to the village level.</p> <p>Coconut: Real-time tabular summary results, graphics and detailed mapping to the household level. Real-time tracking of case follow-up and new interventions.</p>	<ul style="list-style-type: none"> • MEEDS and Coconut are an integrated SMS-based system and tablet web-based system, • Mobile technology fully integrated, • Successfully implemented on both islands of Zanzibar • Rapid case reporting, • Real-time tabular output of key variables makes it easy for management to track progress real time, • MEEDS data are used to calculate supply orders. 	<ul style="list-style-type: none"> • Cases from extensive private sector not captured, • Limited capture of baseline data, • Does not currently capture intervention quality, • No mapping to where case was acquired, • Denominator (population) data not captured with Coconut.
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B. Linkage between national, regional and global surveillance systems

Ideally, national malaria control and elimination systems would link seamlessly with related regional and global structures, providing real-time intelligence about outbreaks and areas of transmission. This would lead to appropriate allocation of national and regional resources and more timely targeted action. Such linkages could prevent outbreaks from spreading locally, regionally and internationally and reduce risks of malaria reintroduction. However, to achieve these goals, sufficient resources for data analysis as well as significant political and financial commitment are all necessary to ensure timely sharing of useful data with participating countries.

There have been attempts to introduce regional and global databases for infectious diseases, such as the dengue surveillance system established by WHO. This system began as DengueNet, which collected and aggregated data globally, but due to difficulties with reporting and countries' reluctance to share data publicly, current dengue surveillance is organized regionally and data are not openly available. However, this system is being expanded to the global level to aggregate regional data and estimate the global burden of dengue. To avoid pitfalls of the initial global system, WHO is engaging a broad range of stakeholders to reach consensus on the minimum essential data and outputs at the national level. The creation of a global system could be useful and influential for policy and advocacy since its purpose is to track larger multi-national trends and offer support through technical assistance and financing when needed during outbreaks. The challenges of establishing and implementing the global dengue surveillance system should be kept in mind if a similar system for malaria is considered.

The two most successful international disease databases are based on reporting of syndromes: acute flaccid paralysis for polio and flu-like syndrome for influenza. The Global Influenza Surveillance and Response System is a prime example of global organization for outbreak response. This system has existed for 60 years and collects global data on suspected and confirmed influenza cases to inform outbreak response and contribute to vaccine development. The online platform, FluID, is in the early rollout phase, demonstrating the evolution of a surveillance system to include information technology advances.⁵³

In efforts to facilitate international malaria data sharing, WHO now coordinates a situation room that is focused on the ten African countries with the highest malaria burden, bringing country representatives together virtually every two weeks to discuss stock control, funding issues and to track current and potential outbreaks. Regional "situation rooms" would also be helpful for malaria eliminating regions. Data sharing where populations are moving across borders will facilitate the ability to eliminate the disease. We believe this approach would be useful for regional cooperation for malaria elimination. At the global level, WHO is in the process of convening international malaria experts to discuss the minimum essential data for surveillance which ultimately could also facilitate and encourage cross border data sharing.

Database linkage between countries and within regions is difficult and often lacking, yet this is not entirely surprising given that within some countries multiple unlinked surveillance databases exist. However, as more countries move towards elimination and cross-border and regional malaria elimination initiatives are implemented, data sharing should be encouraged, whether the NMCP encourages informal information sharing between malaria program officers, or publicly or privately between countries.

Conclusions and recommendations

After reviewing the evidence of what is needed for a robust and action-oriented malaria elimination surveillance system, we believe that the following recommendations should be implemented:

1. ***Malaria must be a notifiable disease.*** In countries pursuing malaria elimination, real-time reporting must be required by law and appropriately enforced in all sectors caring for malaria patients, including the private

sector and militaries. This should include integration into a notifiable disease reporting database and negative diagnostic test reporting. Such actions will help achieve elimination and ensure that malaria does not resurge.

2. ***Expert epidemiological and information technology oversight of surveillance is crucial.*** Committed, qualified and motivated surveillance staff at the NMCP and provincial levels is critical. Human resources to support data analysis, including surveillance database managers and epidemiologists who can program database queries, analyze and interpret data, are required. Monthly surveillance review meetings led by surveillance officers will create an opportunity for feedback and discussion of best practices. Human resource capacity and on-going training are essential for the long-term success of elimination efforts, and will support disease control more generally within the health system. Minimum and ideal human resource and training requirements must be outlined and implemented.
3. ***The malaria elimination database must be manageable by the NMCP.*** A malaria elimination database cannot be unnecessarily technical. The database must provide a framework to guide strategic decision making and support the effective management, coordination, and implementation of interventions, particularly at the administrative levels of the NMCP. While it must be able to effectively cross-talk with the notifiable disease-reporting database for case reporting, it does not necessarily need to be integrated within the notifiable disease database. All levels of the malaria control program, from the community to the national level, should receive information from the system, though the server and database should be fully managed by the NMCP.
4. ***Standardized methods for malaria surveillance with targeted response are needed.*** A key element of malaria elimination programs is rapid and appropriate response to malaria cases. Standardized and streamlined methods and indicators will improve consistency and decision-making. The interventions will vary by location and population, but standardized operating procedures must be developed and implemented in all locations to eliminate the disease. In addition to minimum essential indicators, a common reporting format to facilitate data sharing is important. We recommend standardized methods be adapted to existing surveillance systems.
5. ***An effective surveillance system must feed information back to the communities.*** In this review, we found few examples of systems that rapidly fed back surveillance findings to the community-level stakeholders. For surveillance to function as an intervention, real-time feedback and effective response are essential. Intervention timing, coverage and effectiveness must be captured and monitored as part of the system.
6. ***A surveillance system is only as good as the data captured and reported.*** Accurate malaria diagnosis is critical to ensure the system functions as an effective intervention. Case confirmation is critical and will be a key method to track quality in the system. WHO has developed several standardized strategies to improve diagnostics quality, such as microscopist accreditation, standardized rapid diagnostic test training, slide cross-checking and external quality assurance.
7. ***A geographic information system (GIS) and decision support system are crucial.*** Malaria elimination surveillance systems must include spatial data at the likely location of transmission whenever possible. Mapping cases will guide effective, targeted response, which is currently lacking in most regions. We recommend the GIS and SDSS being used in Vanuatu and the Solomon Islands as the model system to be taken to scale in SE Asia. The system will need to be adapted to forest malaria and to capture mobile and migrant populations.
8. ***Operations research.*** A dozen or more potential interventions are available, ranging from the standard ITN, IRS and ACTs to insecticide-treated clothing, repellants, mass drug administration and chemoprevention. Operations research, which should not be confused with operational research, is used routinely by industry

to optimize manufacturing methods and it has not been used effectively in public health. We recommend experts design an operations research model for malaria elimination initially using existing epidemiology and intervention data. Operations research will allow the selection of the best combination of interventions to implement initially and then, based on actual effectiveness reported by the surveillance system, the malaria program can iteratively add or change interventions until elimination is achieved. The approach will allow for continuous learning and adaptation (see UCSF Global Health Group Background Paper *Program Management Issues in Implementation of Elimination Strategies*, 2014).

9. **Adherence and resistance monitoring should be a routine part of the surveillance system.** The surveillance system can provide improved treatment outcomes by monitoring medication adherence. Information about emerging drug resistance can be collected by sampling for parasitemia after treatment (e.g. Days 3, 28 and/or 42). When treatment is provided through DOT, such sampling will indicate emerging drug resistance and have a much larger reach than traditional therapeutic efficacy trials in sentinel sites. If treatment is not given under DOT such sampling would provide evidence of emerging drug resistance or lack of adherence. Molecular markers can define *P. falciparum* treatment failures; standard and emerging markers for drug resistance are available.⁵⁴ This approach will contribute to understanding about drug resistance and medication adherence, informing strategies to address these challenges.
10. **Locally appropriate technologies can help support data quality improvements.** New Internet and communication technologies, such as mobile phone and web-based systems, can help improve reporting rates, timeliness and data quality. Such technologies need to be appropriate to the local context.
11. **Communication for all working on malaria surveillance should be free of charge.** Open communication between all levels of the surveillance system is essential, including communication with community health workers. Impediments to open communication must be minimized. We identified a few examples of companies donating mobile phone minutes or data transmission to support malaria elimination efforts. Such mobile phone minutes could be used as incentives to improve reporting and response.
12. **Real time sharing of malaria data across borders is needed for malaria elimination to be successful.** Regional collaboration must be implemented effectively in most of the world for malaria elimination to be successful. This is particularly urgent in SE Asia, where untreatable malaria is emerging again and migrants are likely to be the primary malaria transmission reservoir. Currently there are few functioning cross-border collaborations. Ideally, surveillance systems would be unified across countries. This is unlikely to actually occur because current surveillance systems have evolved differently. However, establishing standard measurements, such as the location of the transmission event and targeted intervention coverage and effectiveness, could be communicated routinely. Regional “situation rooms” in elimination areas, including the Greater Mekong sub-region, could contribute to effective and meaningful cooperation.
13. **Ensure political and financial commitment.** Harmonizing existing surveillance systems will require both political and financial commitments in the short and long-term. In the short-term, commitment is needed to bring stakeholders together to develop political and financial capital for malaria elimination surveillance systems. In the longer term, commitment is needed to maintain a cadre of workers who can work with the software and adapt it to fit changing circumstances. Involving stakeholders in the development of the system and giving them ownership will smooth adoption and sustain funding.

Many new technology developments to improve surveillance for malaria elimination appear attractive for investment. However, an investment in ICTs is not a panacea; a surveillance system is only as good as its implementation. An excellent surveillance system should be at the core of malaria elimination programs to

ensure that all cases are detected and responded to in an effective and timely manner. Investment in robust, response-focused systems is essential to achieve elimination goals.

Appendix A: Interview guide for surveillance systems to facilitate malaria elimination

The Malaria Elimination Initiative within the Global Health Group at UCSF is in the process of researching and drafting a background about surveillance for malaria elimination. The purpose of this paper is to inform future strategy, policy, programming and research related to malaria surveillance systems, particularly about how to connect them at the national, regional and global levels. We are documenting strategies that have already been tried and either succeeded or failed, as well as those currently being tested or implemented. We are also interested in ideas about what should be done in the future.

With this in mind, we would like you to tell us about your experiences with and viewpoints on malaria surveillance. We will not use your name or the content of any material you send to us in our background paper - your responses will be confidential and serve to improve our understanding of malaria surveillance .

1. In addition to any background documents you have provided, what else can you tell us about the work you are doing, and how malaria surveillance fits in?
2. What are the components of ideal surveillance for malaria elimination? What information is essential?
3. What information, in addition to essential information, contributes to a complete surveillance system?
4. What are the leading surveillance systems to support malaria elimination operations? Who has taken them to scale successfully? What are the key gaps?
5. Can you comment on the WHO document "Disease surveillance for malaria elimination: an operational manual"? What are its strengths and limitations?
6. What is the role of regional surveillance systems for malaria elimination? Are there functioning systems that we can use as a model? What prevents effective regional surveillance?
7. Thinking about disease surveillance generally, do any diseases or surveillance systems come to mind that we should look into as models for malaria?
8. Should other diseases be incorporated with malaria surveillance? Which diseases? Why?
9. Thinking about malaria surveillance, what are the three biggest challenges to address the issue? Why?
10. How do errors in malaria diagnosis affect a surveillance system? How do you think it should be addressed?
11. We are particularly interested in using technology to improve malaria surveillance, please help us understand what already exists, and what potential exists for future improvements .
12. What applications of IT or mobile technology could improve or contribute to malaria surveillance? Are there any other innovative/novel approaches?
13. What strategies would you research, test or implement to improve malaria surveillance if the decision was up to you and funding was not a concern?
14. Who (or what organizations or groups) should we speak to about malaria surveillance, particularly about ongoing programming and research and evaluation?
15. Are there any documents or other resources that we should review?
16. Is there anything else you would like to share with us about surveillance for malaria? Are there any questions you think I missed?

Appendix B: Selected malaria surveillance systems functioning at scale

Country	System Description	Data Capture	Outputs	Strengths	Challenges and Next Steps
Cambodia	<p>Malaria Information System (MIS) is a stand-alone system developed in MS Access.¹² Two additional pilot systems communicate with MIS through mobile technology:</p> <ul style="list-style-type: none"> • Day 0 Alert System (DOAS) uses a cloud-based MySQL database. • Day 3 Alert System (D3AS) programmed in Frontline SMS freeware.¹² Data storage for MIS is an Access database at the MoH. <p>Reporting completeness and data verification methods</p> <ul style="list-style-type: none"> • >98% of cases from government facilities and CHWs are reported, • DOAS and D3AS have automated data checks, • Routine data audits compare system records to source documents. <p>Coverage: MIS is in all 45 malaria-endemic operational districts (OD) covering population at risk of ~3.2M. Currently DOAS is in 3 OD with planned scale-up to 10 ODs by 2015. D3AS is located in some areas with artemisinin-resistant malaria.</p>	<p>Baseline and imported data</p> <ul style="list-style-type: none"> • MIS: Village and location, distance to health facility, census data, CHW information, public and private facility type and location, ITN distribution to village level. <p>PCD case notification:</p> <ul style="list-style-type: none"> • MIS: Data entered at OD level, monthly updates with automatic capture in central database. Data include case deaths from facility registers, CHW RDT-tested and positive cases. • DOAS: CHWs enter five-digit code: species, age, sex, RDT result, phone; facilities enter same plus village code. Immediate SMS for each case to management and Day 28 reminder to collect filter paper in some areas. • D3AS: Reports Day 3 positive smears within 72 hours, sends an SMS to MIS which automatically forwards to malaria officer. Data captured are the same as for DOAS. <p>Additional: Pilot web-based malaria commodity stock-tracking system.</p>	<p>Automated tables and graphs</p> <ul style="list-style-type: none"> • Summary tables: uncomplicated/severe malaria and malaria deaths with estimated coverage with nets; • Tabular results by locations and date. Case data are broken out by location and time period with percent change reported. • Graphic displays of the above and malaria patterns in cross-border areas. <p>Maps</p> <ul style="list-style-type: none"> • MIS: Cases, intervention coverage, staff and facilities to village level. • DOAS/D3AS maps cases to village level. • In a one-district pilot the S\system maps each newly diagnosed case using Google Earth . <p>Reports: Five-page monthly malaria bulletin with online access to the same information available real-time.⁴²</p> <p>Analytics: As above, plus exporting of data for additional analysis. DOAS: In some areas, atovaquone-proguanil is followed-up with Day 28 reminders.</p>	<p>MIS</p> <ul style="list-style-type: none"> • Being integrated with on-line HMIS, • Intervention coverage, health facility, and census data imported, • Tracks severe malaria and deaths, • Large population covered, including all malaria-endemic areas, • CHWs with limited education successfully submitting malaria data • Malaria incidence and intervention coverage can be graphed/mapped for any location or user group to village level, • Automatically generated quarterly malaria bulletin. <p>Pilot DOAS and D3AS:</p> <ul style="list-style-type: none"> • SMS/web-based real-time notification system, • Integrated data verification methods, • DOAS: Free SMS donated by company, SMS when case identified, SMS reminders for patient follow-up, • D3AS: Drug-resistance monitoring with detailed mapping. 	<p>Challenges</p> <ul style="list-style-type: none"> • Not open source, • Pilot mobile technologies not taken to scale, • Coordination between partners is challenging, • Large private, migrant and military sectors not captured, • For most of Cambodia, data aggregated monthly, real-time data a challenge, • PCD cases not confirmed in eliminating areas, • Lack of sufficient decision-making and response to available data, • DOT/treatment outcome monitoring not yet widely done or captured, • Does not capture time-to-case reporting, new interventions or intervention quality, • Case follow-up challenges, • Stock tracking challenges, • No mapping to household level or where case was acquired. <p>Next Steps</p> <ul style="list-style-type: none"> • Identify sufficient resources, • Pilot new interventions, • Scale successful pilot projects.

	System Description	Data Capture	Outputs	Strengths	Challenges and Next Steps
China	<p>Two integrated web-based systems with the aim to achieve malaria elimination. One system is for febrile illness reporting and the other is for focus investigation and intervention tracking. Data storage is in a relational database at the national Centers for Disease Control.¹⁷</p> <p>Reporting completeness and data verification methods</p> <ul style="list-style-type: none"> Nearly 100% of malaria cases are entered into the system, Automated algorithms of various types do data checks, Call backs by malaria staff to complete missing and check inconsistent data, Routine data audits. <p>Coverage: All of China covered (population 1.4B) with > 90% febrile diseases captured, including 3815 malaria cases between Jan. and Oct. in 2013 (26,873 malaria cases in 2008).</p>	<p>Baseline and imported data</p> <ul style="list-style-type: none"> Maps to commune level, Data from 49 sentinel sites includes entomology, serology and drug resistance surveillance. <p>PCD case notification: Health staff submits hard copy data at the township level within 24 hours. SMS alerts are immediately sent to Provincial Health Officers. Data include date, facility, reporting person, patient info, diagnostic result with method, and treatment.</p> <p>Case investigation: One-page form completed within three days. Data entered as above, and include repeat microscopy or PCR, and travel history.</p> <p>Interventions</p> <ul style="list-style-type: none"> Focus investigation/ intervention (e.g. ACD, vector control, health education) within seven days. Active fever screening every 10 days in areas with high incidence. 	<p>Automated tables and graphs Malaria incidence by species, proportion of cases confirmed, proportion of cases imported, number of deaths, blood examination rate, slide positive rate, annual parasite index, provincial/seasonal/gender distribution.</p> <p>Sentinel sites: human biting rate, proportion of particular vector, treatment failure rate.</p> <p>Maps: Spatial disease distribution from the commune to the country level.</p> <p>Reports: Monthly ministry of health report and annual WHO report.</p> <p>Analytics: As above, data can be exported for additional analysis.</p>	<ul style="list-style-type: none"> Web-based system integrated with notifiable disease reporting, 1-3-7 is an easy-to-use framework that tracks time to case notification (Day 1), case investigation (Day 3), focus investigation and interventions (Day 7), >80% febrile illness and nearly 100% of malaria cases captured, Successfully implemented in all of China, Data quality checks, Real-time case reporting by SMS to surveillance officer, Case confirmation with repeat microscopy and PCR, Malaria case and focus investigation data are automatically fed into HMIS, Malaria maps to commune level. 	<p>Challenges</p> <ul style="list-style-type: none"> Not open source, Mobile technology not integrated, Although extensive sentinel site data, there is otherwise limited capture of baseline data, Does not capture new interventions or intervention quality, Some interventions are possible in less than seven days, No mapping to household level or to where case was acquired. <p>Next Steps</p> <ul style="list-style-type: none"> Expand functionality to household level and include spatial decision support system (SDSS), SDSS to guide case investigation, focus investigation and interventions using spatial and temporal information.

Country	System Information	Data Capture	Outputs	Strengths	Challenges and Next Steps
Solomon Islands/ Vanuatu	<p>Integrated Spatial Decision Support System (SDSS) framework using a SQL programming language, MS Access database and MAPINFO® GIS software. Data is stored in a relational database, using local, provincial and national based servers for backup.⁷</p> <p>Reporting completeness and data verification methods</p> <ul style="list-style-type: none"> Nearly 100% of cases are reported into the system. Health information system (HIS) data used to cross-check information. Automated SQL-based algorithms to identify obvious data entry errors. Every 6 months, data audits compare system records to health facility source documents. <p>Coverage: All areas of three provinces in Solomon Islands and partial coverage of one province in Vanuatu with a total population > 90K, capturing approximately 1000 malaria cases between 2010 – Oct. 2013.</p>	<p>Baseline data Baseline topographic and infrastructure GIS layers; Household location, population data, IRS and ITN distribution coverage, mosquito breeding sites/ larval surveys, malaria indicator surveys captured with GPS-enabled tablets.⁴³</p> <p>PCD Case notification Health facility staff report by VHF radio or telephone to provincial coordination center within 24-48 hours for entry into Access database. Data include date, facility, reporting person, patient info, diagnosis with method, and travel history.</p> <p>Case investigation: Case classification based on patient info/GIS data above for intervention planning, no laboratory confirmation.</p> <p>Interventions: ACD, vector control and health education. (in select cases) within seven days.</p>	<p>Automated tables and graphs</p> <ul style="list-style-type: none"> Intervention planning by household for IRS, ITNs, Targeted response lists by household for ACD and proactive case detection, Intervention coverage summary data (of above) by household, village, and district levels, Follow-up line lists of households that did not receive desired intervention and where positive cases were detected. <p>Maps: Topographic, health facility and household location, intervention planning, field based operational, intervention coverage, positive case distribution, transmission foci classification and automated “area of interest” response.</p> <p>Automated Reports Rapid case surveillance summary reports, routine surveillance reports every three months, intervention coverage reports.</p> <p>Analytics: As above.</p>	<ul style="list-style-type: none"> SDSS automating geographical reconnaissance methods from prior malaria eradication era, Successfully implemented in four Pacific island provinces, Extensive baseline data captured, Case notification usually in 24-48 hours via simple communication methods, Automated GIS-based queries classify with high-resolution mapping of transmission foci and areas of interest for response, Generates lists to support targeted action, including individual households and populations and known breeding sites, Facilitates budgeting by calculating distance and supplies needed, Readily adaptable to other locations and systems, Customized maps, tables, queries and analysis possible, Incorporates expert knowledge for manual adjustments of automated output data. 	<p>Challenges</p> <ul style="list-style-type: none"> MAPINFO® requires licensing, Mobile technology not integrated, Not linked to HMIS, Limited data quality checks, PCD cases should be confirmed, Lack of sufficient decision-making and response to available data, DOT/treatment outcome monitoring not yet done or captured, Does not currently capture time to case reporting or new interventions or intervention quality, Limited supply tracking, HR constraints, No mapping to where case was acquired. <p>Next Steps Expand functionality to include</p> <ul style="list-style-type: none"> Real-time mapping of the case investigation, Intervention coverage and follow-up operations, DOT monitoring, Geospatial analysis and modeling operations to identify malaria risk in poorly serviced areas and to predict potential breeding sites.

Country	System Description	Data Capture	Outputs	Strengths	Challenges and Next Steps
Swaziland	<p>Three systems: Health Management Information System (HMIS) with monthly reporting of presumptive and confirmed malaria cases. Immediate Disease Notification System (IDNS) with immediate reporting of confirmed malaria cases.^{16,32,55} IDNS is programmed in ASP.net with web-based data entry and a SQL 2008 relational database. GPS-enabled tablets programmed in ASP.net with an MS Access database. Data are uploaded weekly to the Malaria Surveillance Database System (MSDS) built on ASP.net and SQL 2012.</p> <p>Reporting completeness and data verification methods</p> <ul style="list-style-type: none"> • About 59% of malaria cases are reported into IDNS, • Data quality checks conducted weekly on MSDS along with automated algorithms of various types to do data checks, • Audits comparing MSDS to IDNS and HMIS are conducted routinely. <p>Coverage: Entire country (population 1.2 dM), 379 malaria cases captured between 2012-Oct. 2013.</p>	<p>Baseline and imported data Baseline topographic and infrastructure GIS layers. GPS-enabled PDAs used to capture household location, population data, IRS and ITN distribution coverage, potential breeding sites, malaria indicator surveys.</p> <p>PCD case notification: Fifteen reportable conditions, including RDT/microscopy-confirmed malaria, which are dictated through a toll-free hotline. Data are entered on a central server, after which an NMCP surveillance agent receives an SMS of date, facility, reporting person, patient info and case number.</p> <p>Case investigation: Agent visits home within 48 hours. PDA-captured data include GPS coordinates, patient information, travel history, intervention coverage and treatment adherence.</p> <p>Interventions: At case investigation, ACD (in receptive areas) is carried out within 1 km radius using RDTs and LAMP. Repeat visits to ensure high coverage. PDA-entered data uploaded to MSDS weekly.</p>	<p>Automated tables and graphs</p> <ul style="list-style-type: none"> • Case investigation rate, • Case classification, • Intervention coverage, • Numbers screened and RDT and LAMP and positive results during ACD. <p>Maps</p> <ul style="list-style-type: none"> • Investigated cases, • Location of RDT and LAMP positive cases to household level, • IRS and ITN coverage to household level, • Potential breeding sites, • Risk maps based on location of cases with their environment, • To household level documenting index case and households fully, partially, not screened, and not visited in the 1 km radius. <p>Reports</p> <ul style="list-style-type: none"> • Monthly PPT report • Annual narrative report <p>Analytics: Risk factors for malaria determined through case-control design and regression analysis.</p>	<ul style="list-style-type: none"> • Integrated with notifiable diseases reporting system, • Web-based system with fully integrated mobile technology, • Should be readily adaptable to other locations, • Data quality control, • Cell phone provider issues free airtime for PCD case notification, • Case notification is immediate via simple communication methods, • Entire country covered, • Agents' tablets preloaded with detailed maps to household level to improve ACD screening, • PDAs reduce data entry errors and turnaround time in data collection, entry, analysis, report generation and review, • Case investigation facilitates household-level follow-up to determine GPS location and treatment adherence, to assess intervention coverage and to perform ACD, • Temporal-spatial analysis of case distribution, • Friendly, simple to use system for data collection. 	<p>Challenges</p> <ul style="list-style-type: none"> • Not open source, • IDNS not linked to HMIS, • Relatively low reporting completeness to INDS, • Low case reporting from private sector health facilities, • PCD cases not confirmed, • DOT/treatment outcome monitoring not yet done or captured, • Does not currently capture time-to-case-reporting, new interventions or intervention quality, • Difficulty motivating agents to return to homes to achieve full coverage during ACD, • No mapping to where case was acquired. <p>Next Steps</p> <ul style="list-style-type: none"> • Installation of leased line to link IDNS with MSDS, • Reduce ACD screening radius to 500 m to achieve higher screening coverage nearest to index case, • Real-time data submission by agents in the field using mobile 3G network, • Spatial decision support system for automated mapping and analysis.

Country	System Description	Data Capture	Outputs	Strengths	Challenges and Next Steps
Thailand	<p>Stand-alone, web-based system programmed in Java. Data storage is in the Microsoft SQL Server 2005 relational database at Mahidol University. GPS-enabled tablets programmed in Java for patient follow-up, data captured in same server.</p> <p>Reporting completeness and data verification methods</p> <ul style="list-style-type: none"> Nearly 100% of cases from malaria clinics and from malaria post volunteers are reported into the system, Automated algorithms of various types that do data checks, Data audits comparing system records to source documents are conducted on a quarterly basis. <p>Coverage: All areas of artemisinin resistance (eastern and western borders of the country, population > 21m), including 1.5 million febrile cases and 23,000 malaria cases between Jan. and Oct. 2013.</p>	<p>Baseline and imported data Locations of malaria posts and clinics, hospitals, rubber plantations, and villages. Malaria transmission area types by WHO classification.</p> <p>PCD case notification Individual patient data (EP 1 form) entered at malaria clinics within 24 hours, which appear on a case follow-up tablet immediately when Internet access is available.⁴⁴ Data include date, facility, reporting person, patient info, diagnostic result with method and foci classification.</p> <p>Case investigation: One page paper form completed at the time of diagnosis for case classification and intervention planning. See EP 3 form for data.⁴⁴</p> <p>Interventions: ACD, vector control, health education in one to three days (in select cases) with data entered as above. All positive and aggregate negative cases captured. DOT and malaria smears through day 28 in <i>P. falciparum</i> cases captured at patients' homes in a GPS-enabled tablet, data are transmitted immediately.</p>	<p>Automated tables and graphs Tables of cases and malaria species by:</p> <ul style="list-style-type: none"> Nationality, Migrant type (permanent or temporary), ACD results, Foci classification, Patient follow-up table for monitoring of DOT and parasite clearance/cure to household level. <p>Graphs display the above with the ability to select many options with real-time information.⁴⁵</p> <p>Maps</p> <ul style="list-style-type: none"> Generic topographic, health facility, household location, positive case distribution, transmission foci classification. Pf cases both to household level and to where case was acquired. <p>Reports: Monthly Ministry of Health report and annual WHO report.</p> <p>Analytics: As above, tablet-based follow-up form with dates for DOT and resistance monitoring.</p>	<ul style="list-style-type: none"> Web-based system, Mobile technology being integrated, Integrated data verification methods, Implemented in large regions of Thailand, covering all areas of multi-drug resistance, Case notification usually in three hours, always within 24 hours, Interventions usually implemented within three days, Captures DOT real-time with online monitoring possible, Captures Pf resistance real-time with online monitoring possible, Malaria incidence can be graphed/mapped for any location or user group, Aggregate refugee data now being captured, Mapping cases to where the infection occurred (e.g. forest sleeping location 10-20 days earlier), Good potential for large-scale operations research 	<p>Challenges</p> <ul style="list-style-type: none"> Not open source, Not linked to HMIS, No military data, Hospital-based cases in a separate system, Does not capture data from Southern Thailand, Challenges with migrant follow-up and cross-border information, More extensive baseline data could be captured, such as intervention coverage and forest sleeping locations, PCD cases not confirmed real time, Does not currently capture time-to-case reporting, interventions or intervention quality, Stock tracking not part of the system, Mapping feature not implemented in all areas. <p>Next Steps: Expand functionality to include</p> <ul style="list-style-type: none"> Mapping everywhere, Full foci-case management, Bed net distribution and adherence, Insecticide spraying and Behavior change communication.

Country	System Description	Data Capture	Outputs	Strengths	Challenges and Next Steps
Zambia	<p>DHIS2 is a web-based health information system programmed in Java.⁴⁷ Three unique steps for malaria are in place:</p> <ol style="list-style-type: none"> 1. Improved data quality at health facility level, 2. Reduce transmission with community-based interventions, 3. Case-based follow-up using CHWs. <p>Data storage is in Postgre SQL relational database. Mobile phones programmed in Java use the same database.</p> <p>Reporting completeness and data verification methods</p> <ul style="list-style-type: none"> • 85% cases are captured in the system, • Automated algorithms and dashboards are used for data verification,⁴⁸ • Data audits comparing DHIS2 records to patient registers occur routinely. <p>Coverage: Areas of low transmission in two provinces (population 6.5M). >800,000 febrile cases with 140, 824 malaria cases reported between Jan. and Oct. 2013.</p>	<p>Baseline and imported data Census data, administrative boundaries and GPS locations of health facilities/CHW posts.</p> <p>PCD case notification Urban and rural health facility-based staff report by mobile phone weekly. Data include clinic visits, clinical cases, RDT-tested/ positive cases, microscopy-tested/ positive cases, cases by age (<, ≥ 5 years), ACT and RDT stock dispensed/balance available. CHWs report monthly case numbers by mobile phone.</p> <p>Case investigation: CHWs visit houses of positive cases that either they identify or are notified about from a facility.</p> <p>Interventions: ACD with RDT by CHW within 1-2 days, 150m radius around incident case's home. Data captured include number of houses visited, number reporting travel, number tested and treated and number of ITNs provided. Data sent by mobile phone monthly.</p>	<p>Automated tables and graphs Graphs are created and provided in real-time to mobile phones or computers, which summarize malaria case reporting and stock data, with summary data from all reporting areas to the level of individual facilities.⁴⁶</p> <p>Specific graphs include</p> <ul style="list-style-type: none"> • Facility reporting rates, clinical and confirmed malaria cases, • Total outpatient attendance and suspected malaria, • Malaria test positivity rates in suspected cases, • Artemether-lumafantrine dispensed versus treatable malaria cases, • Maps and graphs displaying village and clinic-level positivity and incidence identifying hotspot areas. <p>Reports: Weekly, monthly and quarterly reports, with online access to the same data available real-time.</p> <p>Analytics: Graphs as above. Data may be exported from DHIS2 for additional analysis.</p>	<ul style="list-style-type: none"> • Web-based system, • Steps 1 and 3 integrated with HMIS, • Basic mobile technology integrated, • Open source, free, web-based system , • DHIS2 being adopted by several MoHs, • Strong network of programmers, • Free technical support for core module, • Stock management built into the system, • Integrated data verification methods, • Implemented in large population, • Timeliness and completeness of aggregate data reporting tracked, • Graphs shared with all users with online dashboards⁴⁶ • CHWs with limited education successfully submit data, • Malaria incidence can be graphed for any location or user group to village level. 	<p>Challenges</p> <ul style="list-style-type: none"> • Limited capture of baseline data, • Case data not reported real-time, aggregated weekly (clinic) or monthly (community), • PCD cases not confirmed in eliminating areas, • DOT/treatment outcome monitoring not yet done or captured, • Does not currently capture time-to-case reporting, interventions or intervention quality, • ACD currently executed with RDTs only, • No mapping to household level or where case was acquired. <p>Next Steps</p> <ul style="list-style-type: none"> • Evaluate capabilities of DHIS2 to support full malaria elimination surveillance system to household level, • Increase coverage, • Set specific response thresholds and plan for higher thresholds of malaria transmission, • Continued MoH end-user training.

Country	System Description	Data Capture	Outputs	Strengths	Challenges/Next Steps
Zanzibar	<p>Integrated system combining Malaria Early Epidemic Detection System (MEEDS), Malaria Case Notification (MCN) and Coconut Surveillance.^{52,56,57} MEEDS uses unstructured supplementary service data (USSD) messages to report all cases from health clinics into a PHP database. MCN includes rapid reporting to MEEDS and analysis outputs detailing geo-location of cases, through Coconut Surveillance. Coconut is an Android app (html5 + CouchDB) that leverages MEEDS data to guide household oriented index case follow-ups, with cloud synchronization.</p> <p>Reporting completeness and data verification methods Nearly 90% of cases from government clinics are captured. MEEDS: Regular data audits with HMIS logs. Coconut: Automated algorithms do data checks.</p> <p>Coverage: Both systems cover all areas of both islands (population 1.3M), including 2458 cases in MEEDS and 1695 cases followed up using Coconut to between Jan. and Oct. 2013.</p>	<p>Baseline and imported data Topographical maps to household level.</p> <p>PCD case notification MEEDS: Health workers at public health units send messages for each positive case each day and a weekly summary. Data include all cause visits, malaria tested/positive cases, age (>, <5 years).</p> <p>Coconut: notifies malaria officers of cases immediately via SMS.</p> <p>Case investigation : After receiving the SMS, officers download data to tablets. Officers go to the clinic and case's home usually within 48 hours. Data are captured offline and then uploaded when a mobile network or Wi-Fi connection is available. Data include GPS coordinates of home, household member RDT results, travel history, use of bed nets, etc.</p> <p>Interventions: At the time of case investigation, family members are screened for malaria by RDT and treated if positive. Interactive maps and reports are used to guide focused spraying interventions, etc.</p>	<p>Automated tables and graphs MEEDS: PCD case data are summarized in tables and graphically by health facility and district.</p> <p>Coconut:</p> <ul style="list-style-type: none"> Real-time tabular output of facility reporting, case pickup on tablet, facility/household visits, and household members captured, Various tables such as; % follow-up, % family members positive, age range, % using nets, % travelled, Incidence graphs. <p>Maps MEEDS: Weekly summaries of case data. Coconut: Interactive mapping to the household level, with clickable blue dots for cases, red dots if family members were positive; dots can be aggregated by re-sizing the map to a household cluster, village or region.</p> <p>Reports: Monthly Ministry of Health report and annual PMI/WHO report.</p> <p>Analytics: As above</p>	<ul style="list-style-type: none"> MEEDS and Coconut are an integrated web-based system using only mobile technology, USSD messages are free with guaranteed delivery, Coconut is free and open source and should be readily adaptable to other locations at low cost, CouchDB can operate offline and synch when a data connection is available, Implemented on two islands, Data quality monitoring, Rapid case notification, Symptomatic military cases captured, Completeness and timeliness tracked, ACD, intervention coverage assessment and education within about two days, Real-time tabular output of key variables makes it easy for management to track progress real time, Malaria incidence can be graphed/mapped for any location or user group to village level, MEEDS data are used to calculate supply orders. 	<p>Challenges</p> <ul style="list-style-type: none"> MEEDS USSD gateway is proprietary application operated by the network provider, Not linked to HMIS, Cases from extensive private sector, migrants and military not captured, Limited capture of baseline data, PCD cases should be confirmed, DOT/treatment outcome monitoring not done or captured, Does not capture new interventions or intervention quality, ACD currently uses RDTs only, No mapping to where case was acquired, Denominator data not captured with Coconut. <p>Next Steps</p> <ul style="list-style-type: none"> Case-control studies with Coconut to estimate intervention effectiveness, Mass screen and treat vs. MDA effectiveness.

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